Ion Source Choices - An H- Source for the High Intensity Neutrino Source

By
Douglas P. Moehs[1], Robert F. Welton[2], Martin P. Stockli, Jens Peters[3], James Alessi[4]

Abstract
The High Intensity Neutrino Source (HINS) program at Fermilab (formerly the Proton Driver) aims to develop a multi-mission linear accelerator (LINAC) capable of accelerate H^- ions to 8 GeV. This paper touches on the ion source requirements for the HINS and discusses long pulse length testing of three ion sources which appear to have the capability of meeting these requirements.

Introduction

The High Intensity Neutrino Source (HINS) program at Fermilab (formerly the Proton Driver Project [1]) aims to develop a multi-mission linear accelerator (Linac) capable of accelerate H^- ions to 8 GeV providing 2 MW at 30-120 GeV from the Main Injector and 0.5-2 MW at 8 GeV from the Linac, primarily in support of the neutrino physics program at Fermilab. The base design through 110 Mev calls for multiple room temperature and super conducting cavities to be driven by a single 325 MHz klystron. The RF technology to drive multiple cavities with a single klystron is well understood for β=1. As a first step in the HINS R&D program, Fermilab aims to extend this RF technology to β<1 as well as test spoke resonator cavities [2]. To facilitate this R&D effort, construction of a ~60 MeV Linac at Fermilab has begun. The front end of this Linac will be comprised of an H^- ion source, capable of a 1% duty factor (df), with a magnetic LEBT (low energy beam transport) followed by a commercial RFQ (radio frequency quadrupole). Table 1 shows the HINS RFQ input specifications related to ion source performance. The cited input currents account for the 85% RFQ acceleration efficiency. In addition to these specifications a source life time > 12 weeks and a source availability of better than 95% is desired.

Table 1: HINS RFQ requirements related to Ion source performance

Input Energy	50 keV
Acceleration Efficiency	> 85% of incoming beam exits at >99% nominal energy
Initial operation (phase 1):	3 msec x 2.5 Hz @ 15 mA DC (duty factor 0.75%)
Final operation (phase 2):	1 msec x 10 Hz @ 47 mA DC (duty factor 1%)
Input Transverse Emittance	0.25 π mm-mrad RMS Normalized
Output Twiss parameters	Axi-symmetric: $\beta x=\beta y$, $\alpha x=\alpha y$ equal within +/-10%

[1] Fermilab, P.O. Box 500, Batavia, IL 60563, USA: moehs@fnal.gov
[2] SNS, Oak Ridge National Laboratory, P.O Box 2008, Oak Ridge, TN 37831, USA
[3] Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22607 Hamburg, Germany
[4] Brookhaven National Laboratory, Associate Universities, Inc., Upton, New York, 11973, USA

The advent of the Fermilab HINS increases the need for accelerator based H^- ion sources to operate reliable with long pulse lengths and high duty factors [3]. To avoid the high operating temperatures and thermal stresses associated with elevated duty factors active cooling of the ion source is necessary. In the case of surface plasma source (SPS) size scaling may also be used to distribute the heat load [4,5].

To insure that the HINS beam requirement were achievable an extensive review of potential ion sources was carried out in 2005 and a portion of that work was incorporated into ref. [6]. In this paper, long pulse tests of the SNS RF source, the DESY RF source and the BNL style magnetron are presented. It is believed that each of these sources has the potential to meet the needs of the HINS in the near term. Certainly the ISIS Penning source also operate well at a 1% duty factor but source lifetime remains an issue [7].

Long Pulse Tests

Cesiated SNS internal antenna source

Because the beam parameters of the HINS second phase are very similar to those for the SNS [8] it is expected that the SNS source should be able to meet all of the HINS needs. In 2004 the pulse length of the internal antenna source was extended to 3 ms at 5 Hz (1.55% df) as shown in figure 1. At that time the total RF power to the plasma was limited to about 13 kW, at this df, due to operating constraint of the RF amplifier. Testing of the external antenna is eagerly awaited as internal antenna failures remain an issue.

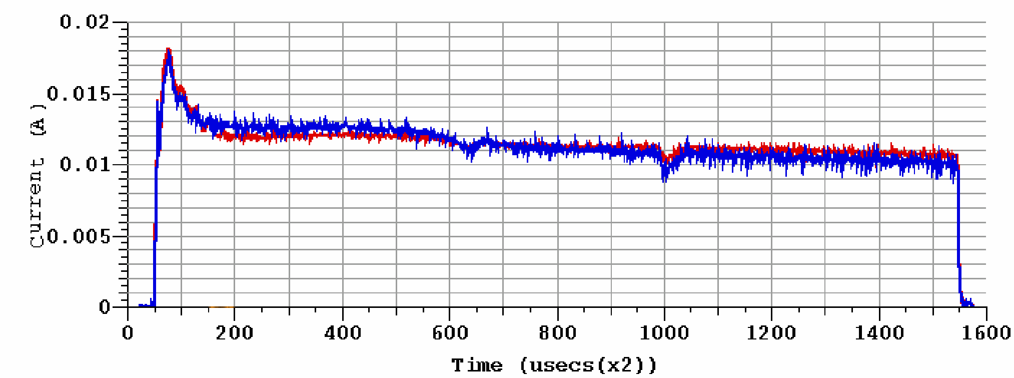

Fig. 1. A 3.1 ms beam pulse from the SNS internal antennae ion source. The 2 traces represent Faraday cup and current transformer measurements.

DESY external antennae source with no cesium

The DESY RF source was tested in January 2006 using an SNS RF amplifier with a peak RF power of around 20 kW. A current pulse from this test is shown in figure 2. Because the source is not actively cooled the df was limited to 0.5%. The droop in the signal is associated with droop in RF power and in the extraction voltage. Work is currently being done to bolster the extraction power supply [9].

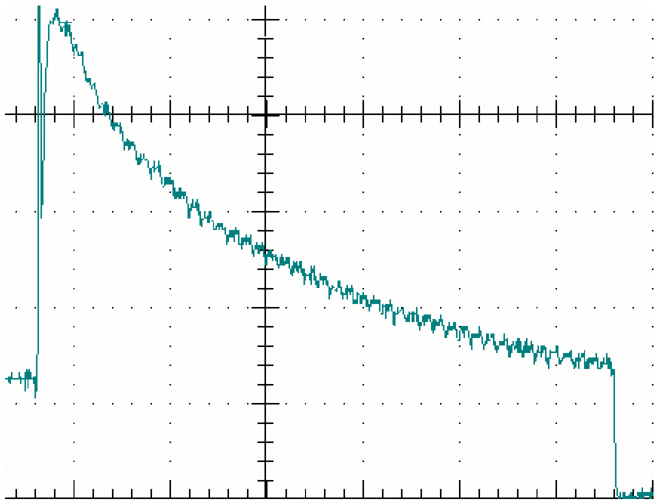

Fig. 2. A 3 ms long pulse from the DESY RF source, one division represents 10 mA by 500 μs. The final offset is due to droop in the current monitor.

BNL magnetron

The BNL magnetron routinely operates at 0.7% duty factor, very close to the HINS df requirement. Further more, multi-slit, Mark style magnetrons have produced 20 ms pulses at very low duty factors [10]. At low currents the magnetron emittance should be sufficient for the HINS and this can be seen in Figure 3, which was created as a magnetron emittance guide. No attempt to normalize or separate out cathode, aperture or LEBT/pre-accelerator types has been made, nor was the measurement apparatus or analysis method investigate or accounted for with the exception of the right most data point which was included twice. In some cases a Gaussian beam approximation was assumed in order to convert fractional emittance to RMS [6].

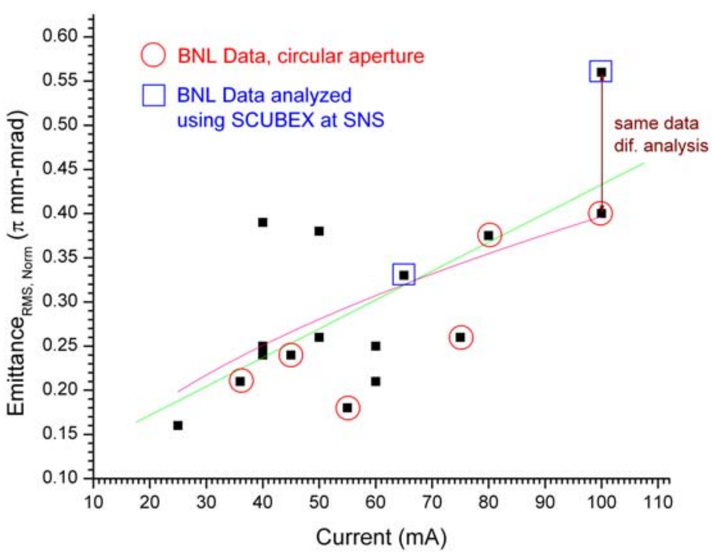

Fig. 3. Magnetron emittance trend verses current. The straight line is a linear fit to the data and the curve line represents a square root fit to the data. The emittance values in this plot were gleaned from the following references [6,11,12,13,14,15,16,17,18,19].

A long pulse test of the BNL magnetron was carried out in February 2006. The pulse length of the online source was extended to 1.6 ms at 6 Hz for about 10 minutes. In this way, the higher temperatures associated with the 0.3% increase in duty factor were avoided. The beam current was 60 mA at the peak and drooped to 40 mA due to arc supply limitations.

HINS Ion Source Status

Based on expediency, cost, operational experience and source longevity a Fermilab magnetron is being adapted to a straight ahead configuration for HINS R&D[20]. Emittance measurements at low currents are being carried out and will be made as a function of time to insure stability during the longer pulse. New switching power supplies able to extend the source duty factor to 1% are being tested and thermal modeling is also being carried. A magnetic LEBT has been constructed to match the beam to the RFQ, which is anticipated in the spring of 2007.

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[1] G. W. Foster and J.A. MacLachlan, “A Multi-Mission 8 GeV Injector Linac as a Fermilab Booster Replacement,” Proc. LINAC 2002, Gyeongju, Korea. Also see: http://protondriver.fnal.gov/

[2]

[3] R.F. Welton, “Overview of high-brightness H$^-$ ion sources,” in *Proc. Inter. Linac Conf.,* Gyeongju, Korea, Aug. 2002, pp. 559.

[4] H.V. Smith, Jr., P. Allison, and J.D. Sherman, “H$^-$ and D$^-$ scaling laws for penning surface plasma sources,” *Rev. Sci. Instrum*., **65**, pp.123-128, Jan. 1994.

[5] D.C. Faircloth and J.W. G. Thomason, “Thermal modeling of the ISIS H$^-$ ion source,” *Rev. Sci. Instrum.,* **75**, pp.1738-1740, May 2000.

[6] D. P. Moehs, J. Peters, and J. Sherman, “Negative hydrogen ion sources for accelerators” IEEE Trans. Plasma Sci., **33**, pp. 1786, December 2005.

[7] R. Scrivens, “Proton and ion sources for high intensity accelerators,” *Proc. Eur. Particle Accel. Conf.,* Lucerne, Switzerland, Jul. 5, 2004, pp. 103-107.

[8] R. Keller, R. Thomae, M. Stockli, and R. Welton, “Design, operational experiences and beam results obtained with the SNS H$^-$ ion source and LEBT at Berkeley Lab,” PNNIB, AIP Conf. Proc. 639, pp. 47-59, May 2002.

[9] K. Müller and J. Peter, “Improving the H$^-$ pulse quality with an active HV droop compensation,” DESY HERA 06-02, January 2006

[10] K. Prelec and Th. Sluyters, “An intense negative hydrogen ion source for neutral injection into Tokamaks,” *6th Symp. on Eng. Problems of Fusion Research,* San Diego, *CA*, Nov. 18, 1975, BNL 10656.

[11] C. W. Schmidt, “An H$^-$ ion source for accelerator use,” PNNIB Conf. Proc., p.123 (1977).

[12] J. G. Alessi, “A circular aperture magnetron for injection into an RFQ,” PNNIB, AIP Conf. Proc. **158**, pp. 419-424, Sept. 1986.

[13] V. Stipp, A. DeWitt and J. Madsen, “A brighter H$^-$ source for the intense pulsed neutron source accelerator system,” IEEE Trans. Nuc. Sci., **30**, pp. 2743-2745, Aug. 1983.

[14] H. V. Smith and P. Allison, “H$^-$ beam emittance measurements for the Penning and the asymmetric, grooved magnetron surface-plasma sources,” Rev. Sci. Inst. **53**, pp. 405-408, April 1982.

[15] J. G. Alessi, talk associated with, “Performance of the magnetron H$^-$ source on the BNL 200 MeV Linac,” AIP Conf. Proc. **642**, pp. 279-281, April 2002.

[16] C. W. Schmidt and C. D. Curtis, “Operation of the Fermilab H$^-$ magnetron source, PNNIB, AIP Conf. Proc. **158**, pp. 425-429, Sept. 1986.

[17] L. Criegee, et al., “The 50 MeV H$^-$ linear accelerator for HERA:LINAC3 collaboration,” Rev. Sci. Inst. **62**, pp. 867-873, April 1991.

[18] R. Welton et al., “Emittance characteristics of high-brihtness H$^-$ ion sources,” PNNIB, AIP Conf. Proc. **639**, pp. 160-173, May 2002.

[19] J. Peters, “Negative ion sources for high energy accelerators (invited), Rev. Sci. Inst. **71**, pp. 1069-1074, Feb. 2000.

[20] D. Moehs and C. Schmidt, “Magnetron R&D – extended duty factor,” this conference, PNNIB Sept. 2006.